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# RESEARCH MEMORANDUM

PRELIMINARY INVESTIGATION OF DOWNWASH FLUCTUATIONS

OF A HIGH-ASPECT-RATIO WING IN THE

LANGLEY 8-FOOT HIGH-SPEED TUNNEL

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# PRELIMINARY INVESTIGATION OF DOWNWASH FLUCTUATIONS OF A HIGH-ASPECT-RATIO WING IN THE LANGLEY 8-FOOT HIGH-SPEED TUNNEL

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## SUMMARY

A series of tests have been made in the wake of a high-speed wing of high aspect ratio at Mach numbers up to approximately 0.90 to determine the fluctuations of the downwash in the zone of possible tail locations.

Serious fluctuations occurred in the wake of the wing. The fluctuations extended beyond the wake boundaries but with decreasing amplitude. For a high angle of attack of the wing ($7^{\circ}$) and high Mach numbers the fluctuations were very large $\left(3\frac{1}{2}^{\circ}\text{ maximum}\right)$ and extended as high as approximately 0.90 chord above the chord line of the wing. For medium angles of attack ($0^{\circ}$, $2^{\circ}$, and $4^{\circ}$) important fluctuations occurred up to about 0.70 chord above the chord line of the wing.

## INTRODUCTION

In the wake of a wing at low angles of attack and at high speeds, there is an irregular vortex motion that, for supercritical speeds, is not stable and that generates pulsations in the flow. The pulsations consist of a variation in the magnitude and direction of velocity and a variation in the static pressure and density. These variations are of importance in airplane design because they may produce tail buffeting. It is necessary to have an indication of the frequency and the amplitude of the fluctuations of the wing downwash in the region of possible tail locations as a function of free-stream velocity and angle of attack of the wing in order to define the proper tail location and structure. Measurements were made to determine the frequency and ampl[redacted] fluctuations in the wake

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of a high-speed wing of high aspect ratio in the zone of possible tail locations.

## SYMBOLS

| | |
|---|---|
| $M$ | Mach number |
| $\alpha$ | angle of attack of wing |
| $\beta$ | angle of fluctuation |
| $\Delta H$ | loss of total pressure in wake |
| $q$ | dynamic pressure |
| $f$ | frequency |
| $c$ | wing chord |
| $F$ | nondimensional coefficient of frequency |
| $V_o$ | free-stream velocity |

## APPARATUS AND METHODS

### Tunnel and Model

The Langley 8-foot high-speed tunnel, in which the tests were conducted, is of the single-return, closed-throat type. The model tested is shown in figure 1 and is described in reference 1. The model has no dihedral and has an effective span of 37.8 inches, a root chord of 6 inches, and a tip chord of 2.4 inches. A vertical steel plate supported the model in the tunnel (reference 1). The downwash instrument was also attached to the vertical plate. The air-stream velocity and Mach number and the corrections used were the same as those used in reference 1.

### Analysis of Problem of Measuring Downwash Fluctuations

Preceding experiments have shown that the flow in the wake of an airfoil has a nonperiodic irregular motion,

with pulsations of intensity and frequency (reference 2). The irregular motion in the wake, which is very complex for the wing alone, becomes still more complicated for a wing-fuselage juncture in the zone of the tail, because in this zone the wing-fuselage interference effects produce still larger fluctuations of velocity, both in magnitude and in direction, and introduce changes in the plane of fluctuation.

Numerous difficulties arise in the application of the results of downwash-fluctuation tests to the design of airplanes. Because vibrations of the tail can be excited by fluctuations in the direction or magnitude of the velocity of the air, by fluctuations in the pressure, or by variations in the turbulence of the flow, it is difficult to determine which is the most important fluctuation. In the absence of an accurate analysis of the problem, an instrument that records fluctuations of the aerodynamic forces is used because such an instrument is sensitive in the same way as the tail to all the variations in the physical characteristics of the flow. Because fluctuations are nonperiodic, exact calibrations of the instrument, in which theoretical corrections that take into account only the difference between a constant and an oscillating phenomenon are used, cannot easily be obtained. An analysis of the results is also very difficult to make because the fluctuations are not periodic and constant with time; therefore a statistical analysis of the results would have to be made, which would require long records. Because the tests were performed in the wake of a small-scale wing model, the law of similitude for applying the scale-model results to full-size airplanes is not known and theories for models in flows similar to that of the wake must be used; however, this procedure is in part arbitrary. An evaluation of the amount of interference produced by the test conditions on the results is difficult to obtain because there are pulsations in the undisturbed flow (turbulence of the stream), inevitable vibrations of the model and support at certain speeds, and aerodynamic interference between the model and support. Tests to determine the characteristics of downwash fluctuations are therefore difficult and the results are less accurate, quantitatively, than the usual results of aerodynamic tests.

Downwash-Fluctuation Apparatus

The sensitive elements used in the instrument for measuring the amplitude and frequency of the downwash fluctuations were made in the form of small airfoils. The sensitive airfoils were fixed near the model trailing edge to the end plates (fixed parts) and the front parts were free to vibrate as a cantilever beam (sensitive parts) as shown in figure 1. Two strain gages, which were placed on the airfoils near the fixed parts, measured the deformation of the airfoils and therefore the fluctuations (fig. 1).

Sensitive elements used in this type of investigation must have high natural frequencies, high sensitivity even at high frequencies, and small longitudinal and transverse dimensions. Because oscillations of about 1500 cycles per second were to be determined, the natural frequencies of the sensitive airfoils were fixed at about 2700 cycles per second. In order to obtain high frequencies and at the same time to have high sensitivity to variations of aerodynamic forces, the sensitive parts of the airfoils were made of aluminum alloy with the weight reduced to the minimum possible, with special attention given to the leading edge. The longitudinal dimension had to be small because the maximum frequency to be recorded was high; the transverse dimension had to be small because the instrument was made up of three sensitive airfoils that had to record the same type of fluctuation.

The sensitive airfoils have a symmetrical circular-arc profile that permits an accurate small-scale construction. The maximum thickness is 8 percent of the chord. This value is large but it could not be reduced because of the space requirements of the strain gages. The danger of vibration of the sensitive airfoils due to their own aerodynamic characteristics and independent of the downwash fluctuations of the typical high-speed-airplane wing, however, was avoided because the sensitive parts were ahead of the maximum thickness and therefore ahead of the position of shock on the airfoils.

Three sensitive airfoils were used and were placed between four end plates. (See fig. 1.) The complete instrument was made with three sensitive airfoils in order to obtain a dynamic calibration. The exact value of the velocity and the law of variation of the aerodynamic force as a function of the direction of the velocity are

unknown for transonic turbulent flow with nonperiodic fluctuations. With an instrument having three sensitive airfoils placed at different angles of attack, this law of variation can be determined for every point and, therefore, the variation of the aerodynamic force can be transformed to the equivalent variation in the direction of flow.

The rear parts of the airfoils were fixed to the end plates and the sensitive parts were free to move in slots cut into the plates. The end plates were held by a vertical support (fig. 1) that was fixed to the plate supporting the model of the wing.

The location of the instrument could be changed easily. All the electrical leads that connected the strain gages to the recording instruments were located in the end plates and the support.

For every fluctuation in the stream, there is a certain airfoil deformation. The maximum deformation of the airfoil corresponds to the maximum deviation of the stream in one direction and the minimum deformation corresponds to the maximum deviation in the other direction. For the three sensitive airfoils the maximum and the minimum deviations corresponding to a given fluctuation can be determined, and the value of the airfoil deformation as a function of the angle of incidence of the sensitive airfoils can be plotted (fig. 2). The two curves in figure 2 give the deformation as a function of the geometrical incidence of the sensitive airfoils. It is therefore possible to find the difference between the maximum and minimum deviations as a function of the angle of incidence of the airfoil and thus of the direction of the velocity. In an evaluation of the data by this method, the assumptions are made that changes in the flow characteristics are small during the time for one fluctuation, that the maximum deviation of the velocity (point at which acceleration is zero) corresponds to the maximum aerodynamic force, and that all the sensitive airfoils have the same aerodynamic characteristics at a given Mach number. The approximation of these assumptions is good.

## Calibration of Instrument and Stream

The following tests were made for the calibration of the system:

(1) The natural frequency and damping coefficients of the airfoils were experimentally determined. These values were used to determine the ratio of indicated amplitude to impressed amplitude as functions of the frequency. This ratio is necessary to calculate the impressed amplitude for high frequencies.

(2) The sensitivity of each airfoil was determined as a function of the angle of incidence and Mach number. This test was necessary to determine whether or not the aerodynamic characteristics of the three airfoils were the same for all velocities and angles of incidence and to determine the sensitivity of the instrument.

(3) A test was made to determine the vibrations of the tunnel stream. This test gave an indication of the tunnel-stream fluctuations that depend on the air-stream turbulence and showed whether or not the aerodynamic phenomena on the sensitive airfoil produced vibrations of the sensitive part.

Tests (2) and (3) gave satisfactory results, which indicated that the stream was regular and that the instrument was suitable for the tests.

# TESTS

All the tests were performed by placing the instrument in different locations along a vertical axis, at a distance 3.1 root chords behind the leading edge of the wing (fig. 1) and at a spanwise station 0.64 of the root chord away from the wing support plate. (This distance corresponds to 10.2 percent of the semispan.) Downwash-oscillation measurements were taken for each instrument location at Mach numbers from approximately 0.76 to 0.90 and at angles of attack of the model of $-2^{\circ}$, $0^{\circ}$, $2^{\circ}$, $4^{\circ}$, and $7^{\circ}$. The range of instrument location was increased for the higher angles of attack, since the wake dimensions were larger.

The exact precision of the data cannot be given because several sources of error difficult to evaluate were present in the tests. The data, for example, were obtained in statistical form from a practical examination of the records. The amplitude and frequency were determined at a limited number of points (fig. 3). Because the selection of the points to be read depended in part on judgment, the data were probably affected by the selections made. The importance of vibrations of the undisturbed stream, interference of the support, vibrations of the model, and vibrations of the support on the final data could not be easily estimated. All these influences, which cannot be eliminated in tunnel tests, can change the amplitudes and frequencies somewhat. A study of the sources of error indicates that the precision of the amplitude is of the order of magnitude of $0.5^{\circ}$ for the larger fluctuations and $0.25^{\circ}$ for the smaller fluctuations. The errors are probably larger for high frequencies and smaller for low frequencies. The amplitude of fluctuation of the undisturbed stream is of the order of magnitude of $0.1^{\circ}$ to $0.2^{\circ}$. No corrections have been applied to the values of the amplitudes and the frequencies.

## RESULTS

The test results are shown in figures 4 to 9. In order to make a comparison of the amplitude of the fluctuations with wake position, the available wake-survey data are also plotted in these figures. The average of the maximum angle of fluctuation $\beta$ for the range of frequency that appears on the records is plotted in terms of the instrument location which is defined in the following manner: The zero location (zero of abscissa scale) is the point of intersection of the wing chord line (as it changes with angle of attack of the wing) and the axis of exploration. The other locations are the vertical distances from the zero location along the axis of exploration and are measured in percent of the wing chord at 10.2 percent of the semispan. Positive values indicate instrument locations above the chord line of the wing. For each fluctuation diagram, three ranges of frequencies found to occur in downwash fluctuations were considered.

The range of high frequency did not change greatly with the angle of attack of the model and the velocity;

however, the low-frequency range was larger. The low-frequency range is plotted in figure 9 for various Mach numbers of the model.

The value of the gradient of deformation of each airfoil in the instrument with angle of flow, which is the sensitivity of the instrument with change of the flow angle, varied with changes in the instrument location and was less inside the wake than outside. Because the fluctuations were neither steady nor regular, their exact values are difficult to determine. The variation of the gradient of deformation was large in the central part of the wake (the deformation gradient decreased about 45 percent in the center of the wake for $M = 0.90$ and $\alpha = 7^{\circ}$), which shows that in this part of the wake the lift gradient of the instrument airfoil decreased. The variations were small when the instrument was outside the wake.

## DISCUSSION

The following observations can be made from the test results:

(1) The fluctuations generally are large in the same zones in which the wake is large (figs. 4 to 8).

(2) The fluctuations increase with the increase in angle of attack of the wing (figs. 4 to 8) and, for low angles of attack, the fluctuations increase noticeably with the increase in Mach number (figs. 4 and 5).

(3) The limits of the zone of fluctuation increase with increase of the angle of attack (figs. 4 to 8). For medium angles of attack ($0^{\circ}$, $2^{\circ}$, and $4^{\circ}$), large fluctuations do not occur above an instrument location of about 0.70 chord above the wing chord line (figs. 5 to 7). For a high angle of attack ($7^{\circ}$), important fluctuations do not occur above an instrument location of about 0.90 chord above the chord line of the wing (fig. 8).

(4) For a high angle of attack of the wing ($7^{\circ}$), the fluctuations are very large $\left(3\frac{1}{2}^{\circ}\text{ maximum}\right)$.

The maximum amplitude, which changes only slightly with Mach number, is not in the central part of the wake but at the edges of the wake (fig. 8).

(5) For low angles of attack, the fluctuations increase for high Mach numbers and are largest in the center of the wake (figs. 4 and 5).

(6) The low-frequency fluctuations are of the order of magnitude of 50 to 300 cycles per second and the high-frequency fluctuations are of the order of magnitude of 1300 to 1600 cycles per second.

The value of low frequencies changes with variations in Mach number and angle of attack. As the velocity increases, the low-frequency values seem to decrease and after reaching a minimum, to increase. The variations in the low-frequency values are not defined exactly. The frequencies become lower with increasing angle of attack (fig. 9).

The decrease of the lift-curve slope of the sensitive airfoil in the zone in which large fluctuations occur probably depends on the fact that the velocity is lower inside the wake than outside; the tail would therefore be less efficient in this zone.

In order to apply the results of the test to full-scale conditions, the assumption can be made that for a given Mach number the nondimensional coefficient of frequency $F = \frac{fc}{V_o}$ must be constant (reference 3). The frequency therefore varies inversely with the wing chord and directly with the ratio of the test velocity to flight velocity. When a $\frac{1}{33.3}$-scale model and a flight altitude of 35,000 feet are assumed, the range of low frequency for full-scale conditions is found to be approximately from 1 to 12 cycles per second, as shown in figure 10, and the range of high frequency is thus from 52 to 64 cycles per second. This law of similitude, which is similar to those accepted for flows like that in the wake, probably gives a good approximation of full-scale conditions. The amplitudes of the downwash fluctuations for a full-scale airplane can be assumed to be the same as those for the model. In the zone of large fluctuations of the downwash, large fluctuations of the tail loads

must therefore occur. The measured fluctuations correspond to a large part of the usual design tail loads of an average airplane and may be several times greater than the usual loads for balancing the tail in level flight.

## CONCLUSIONS

The following conclusions are based on downwash-fluctuation tests made in the wake of a high-speed wing of high aspect ratio in the Langley 8-foot high-speed tunnel at Mach numbers up to approximately 0.90:

1. Serious fluctuations occurred in the wake of the wing. The fluctuations extended beyond the wake boundaries but with decreasing amplitude.

2. For supercritical speeds at a high angle of attack ($7^\circ$), serious fluctuations $\left(3\frac{1}{2}^\circ \text{ maximum}\right)$ occurred at the tail locations and some fluctuations extended as high as approximately 0.90 chord above the chord line of the wing.

3. For medium angles of attack ($0^\circ$, $2^\circ$, and $4^\circ$), a tail location free from serious fluctuations was found to be about 0.70 chord above the chord line of the wing for a tail location 3.1 root chords behind the leading edge of the wing.

4. The more-probable frequencies are of the order of magnitude of 1 to 12 and 52 to 64 cycles per second for a wing $33\frac{1}{3}$ times the size of the model tested.

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3. von Kármán, Th., and Burgers, J. M.: General Aerodynamic Theory - Perfect Fluids. Problems of Non-Uniform and of Curvilinear Motion. Vol. II of Aerodynamic Theory, div. E, ch. V, W. F. Durand, ed., Julius Springer (Berlin), 1935, pp. 280-315.

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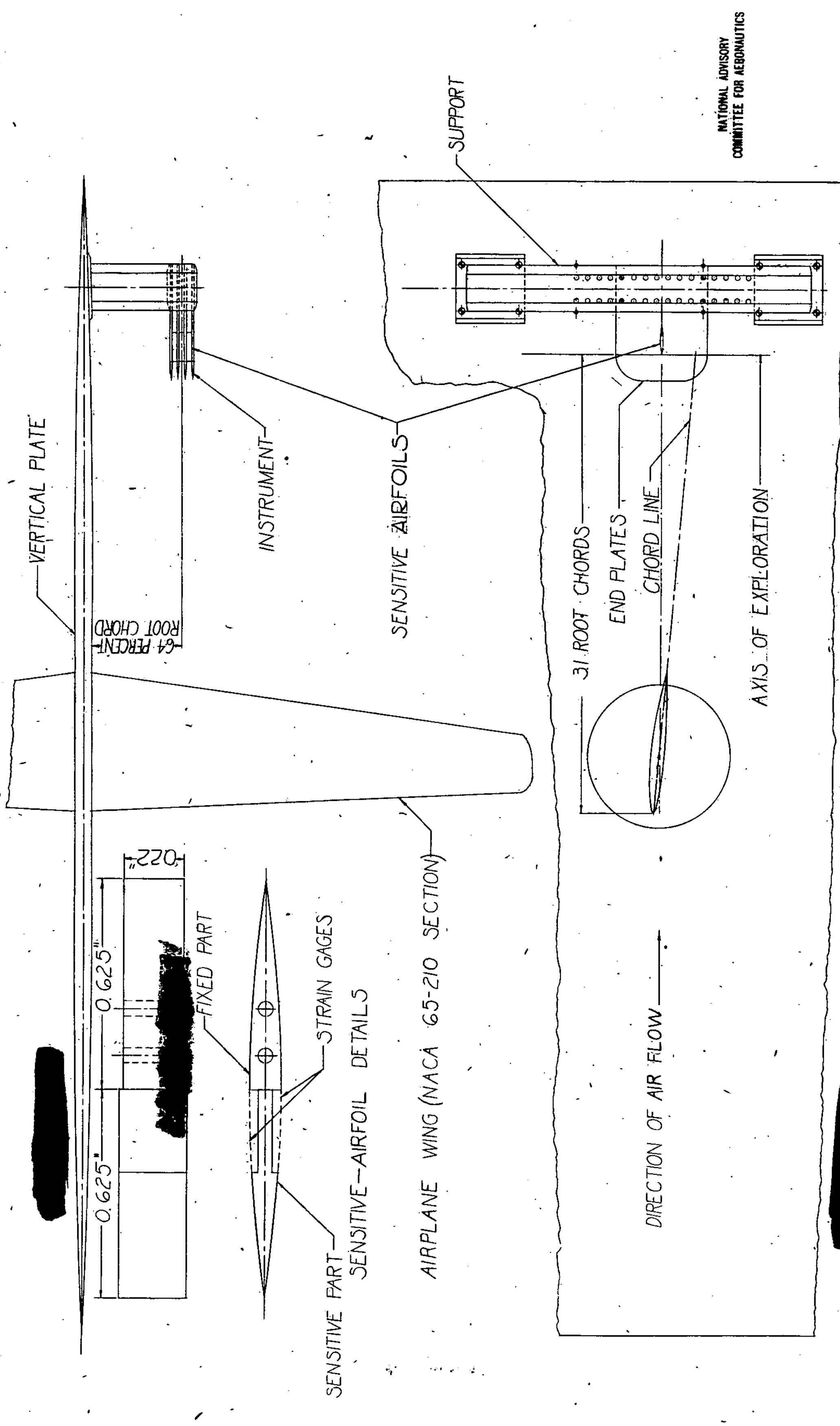


FIGURE 1.- INSTRUMENT DETAILS AND INSTALLATION.

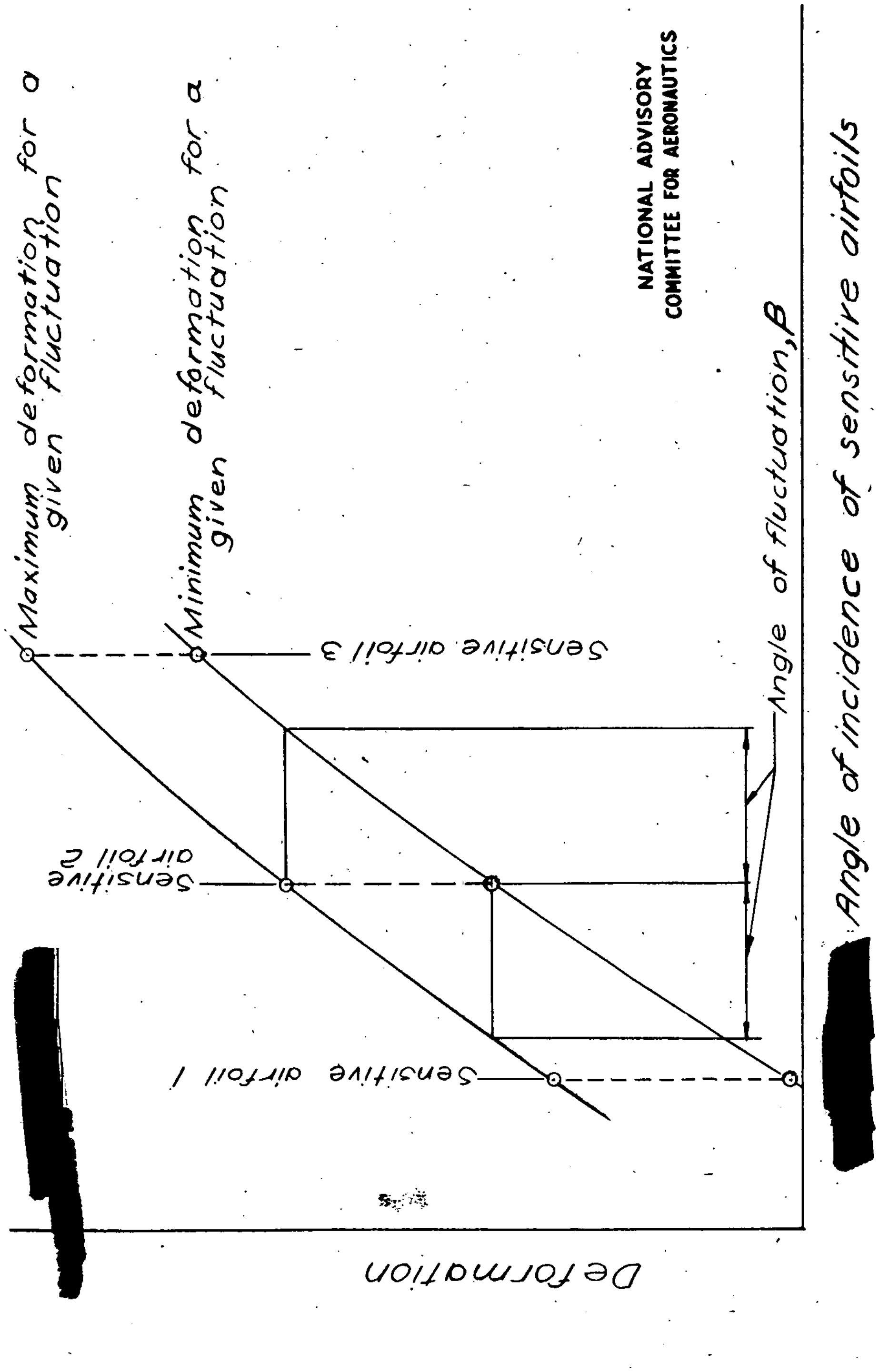


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Figure 2.- Scheme for calculating the angle of fluctuation from the value of the maximum and minimum deformation of the three airfoils.

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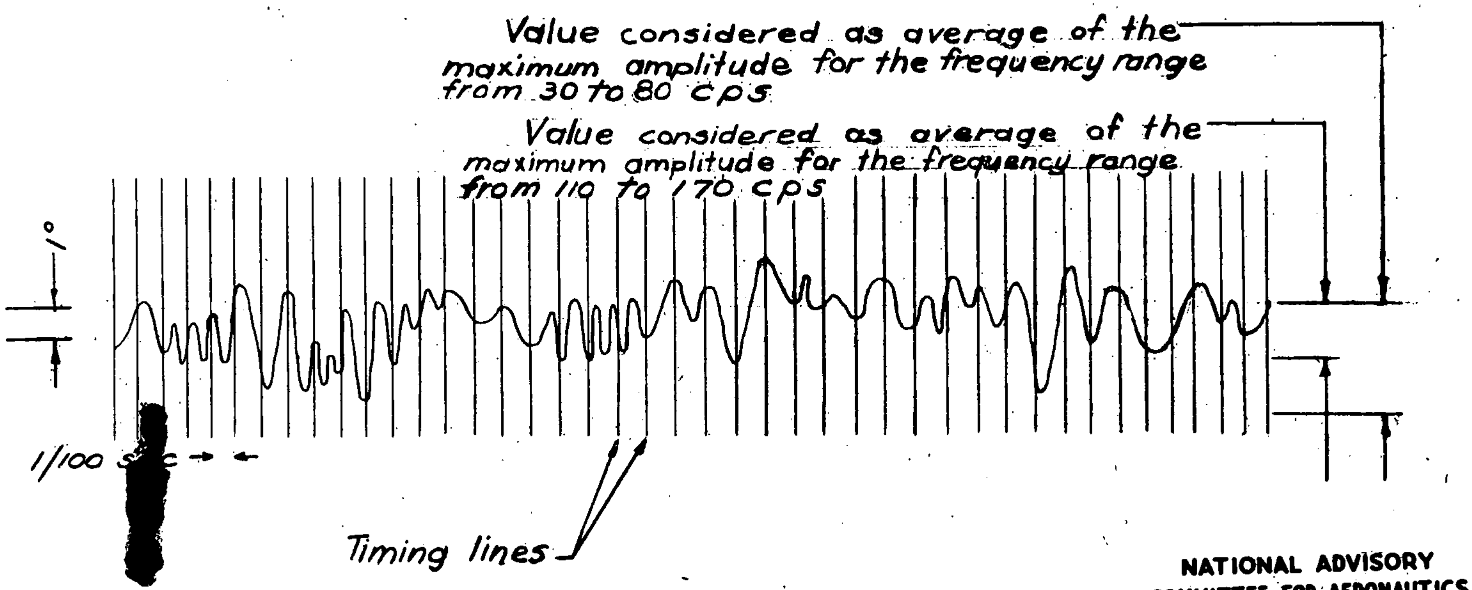


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Figure 3.- Example of the form of the low-frequency fluctuation diagram of the wake. Instrument location 28.4 percent chord above chord line of wing; $\alpha = 7^\circ$; $M = 0.875$.

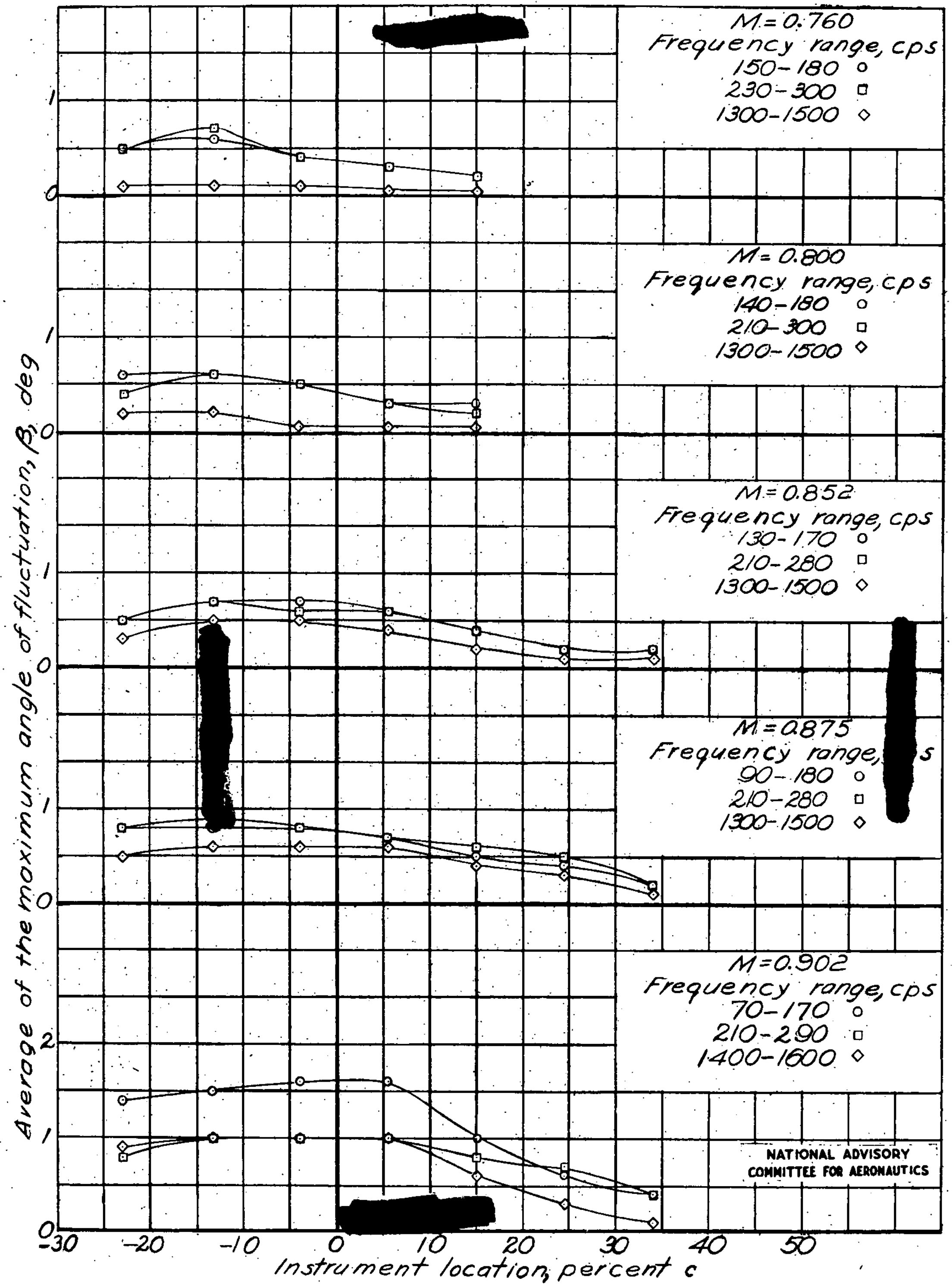


Figure 4.- Maximum angle of fluctuation as a function of instrument location. $\alpha = -2°$.

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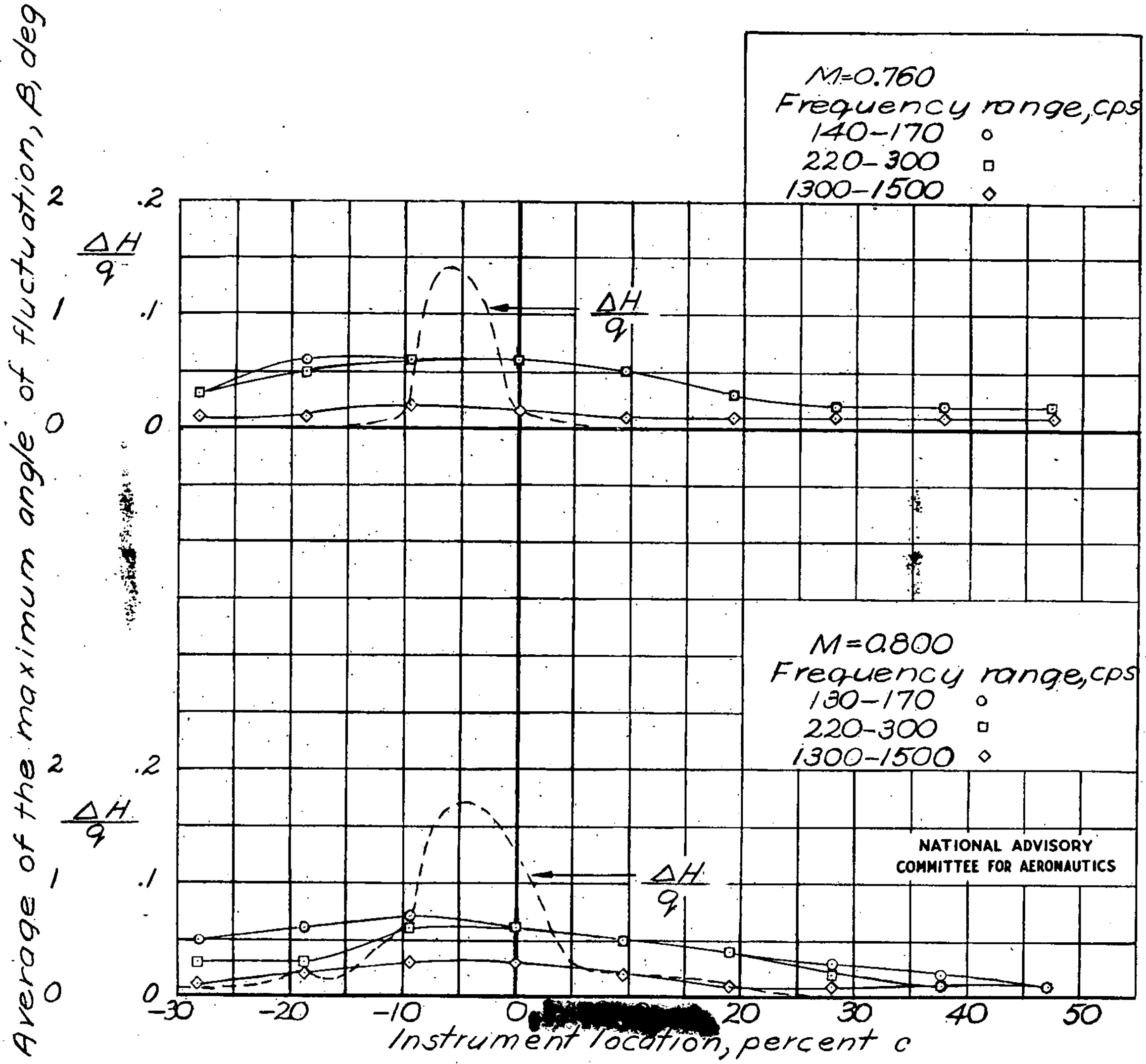


Figure 5.- Maximum angle of fluctuation as a function of instrument location. $\alpha = 0°$.

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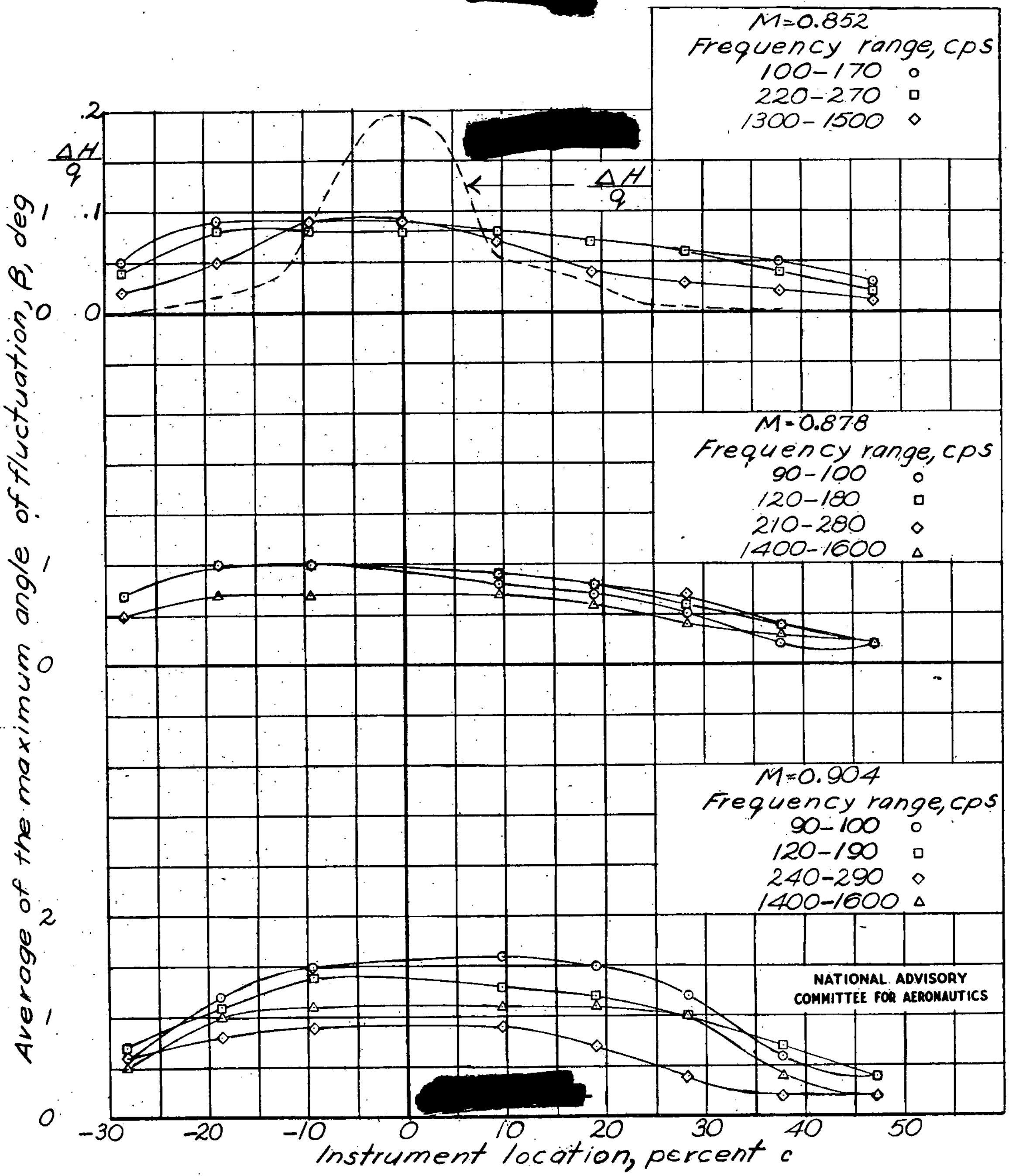


Figure 5.– Concluded.

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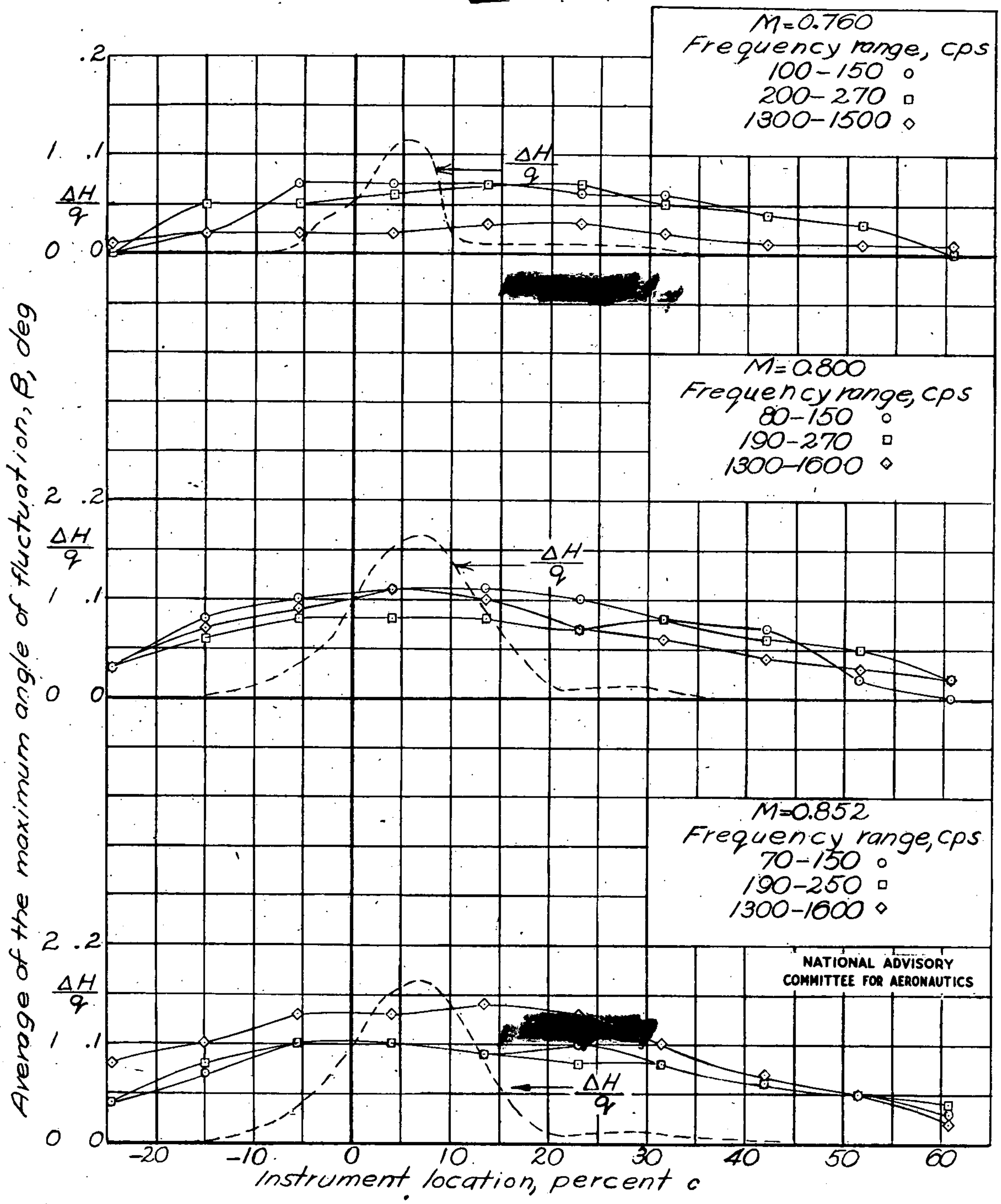


Figure 6.- Maximum angle of fluctuation as a function of instrument location. $\alpha = 2°$.

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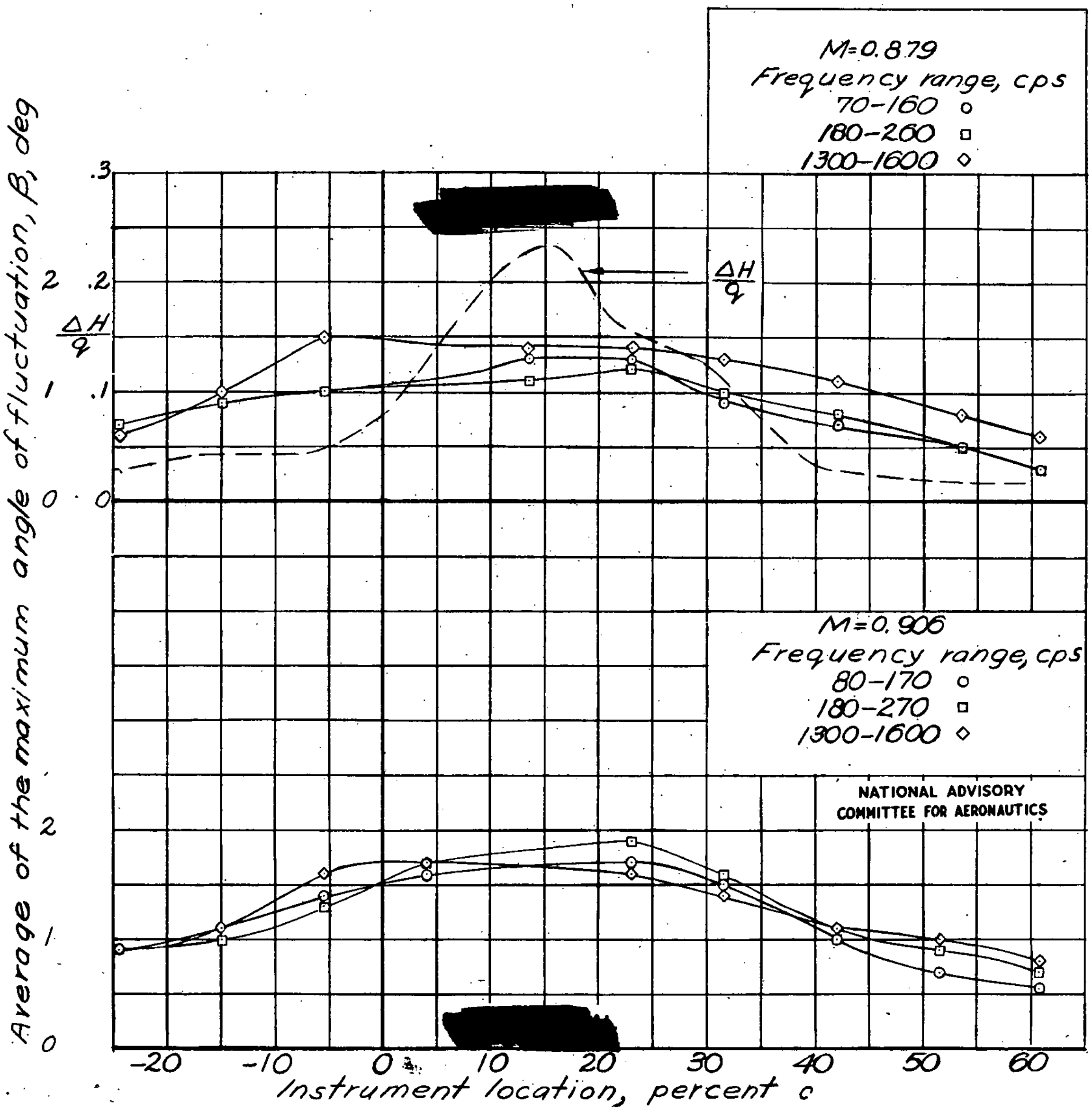


Figure 6.- Concluded.

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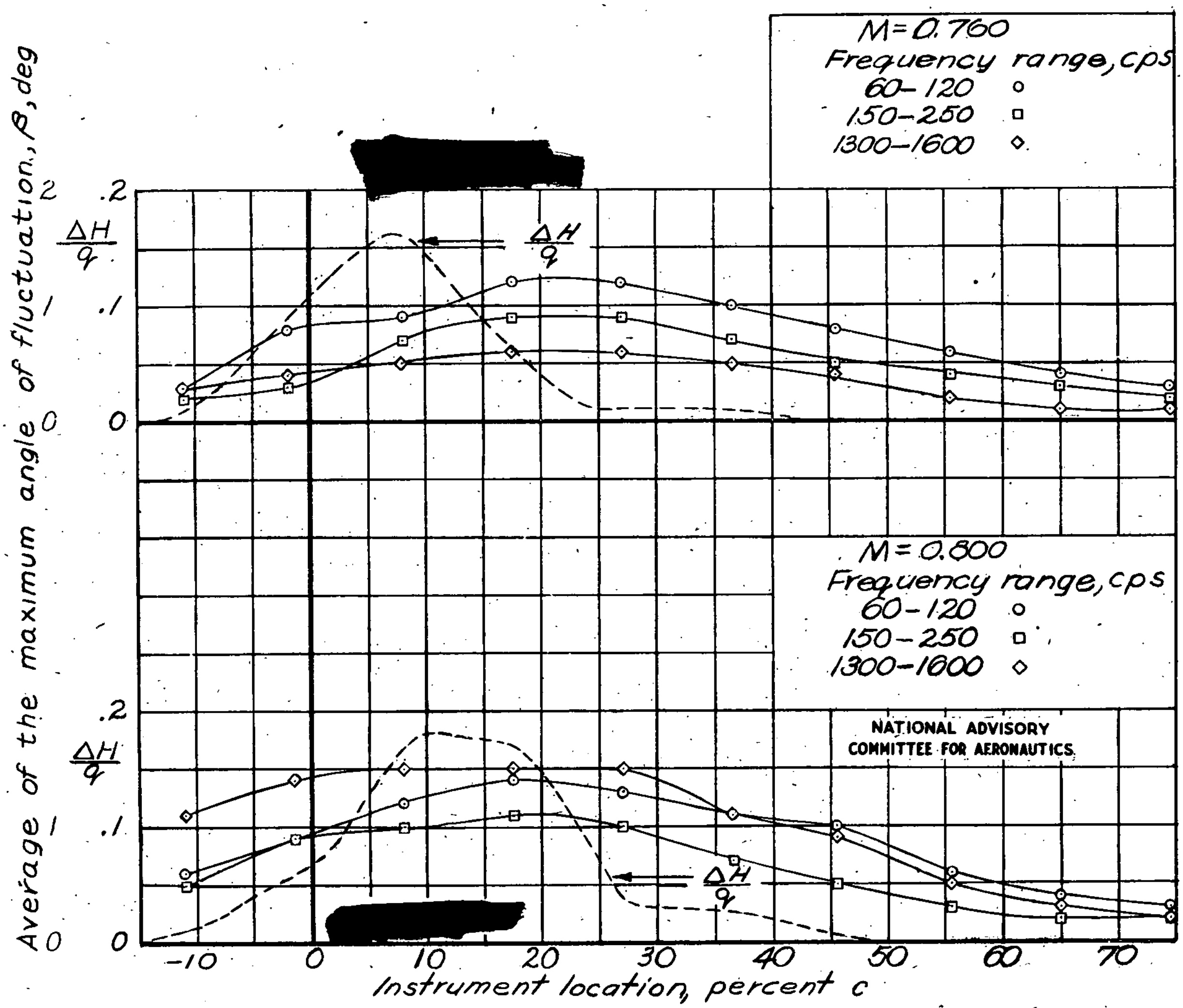


Figure 7.- Maximum angle of fluctuation as a function of instrument location. $\alpha = 4°$.

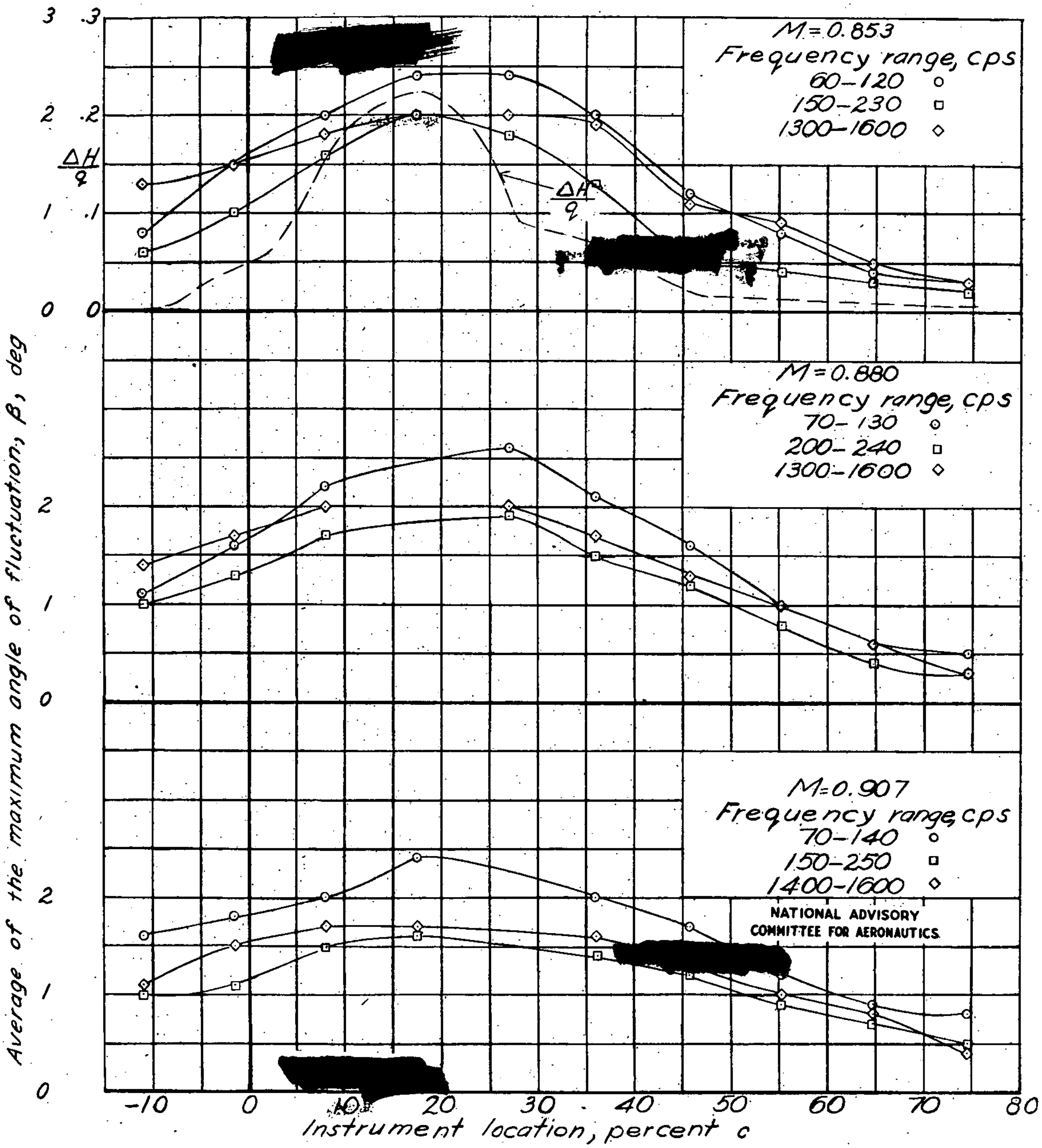


Figure 7.— Concluded.

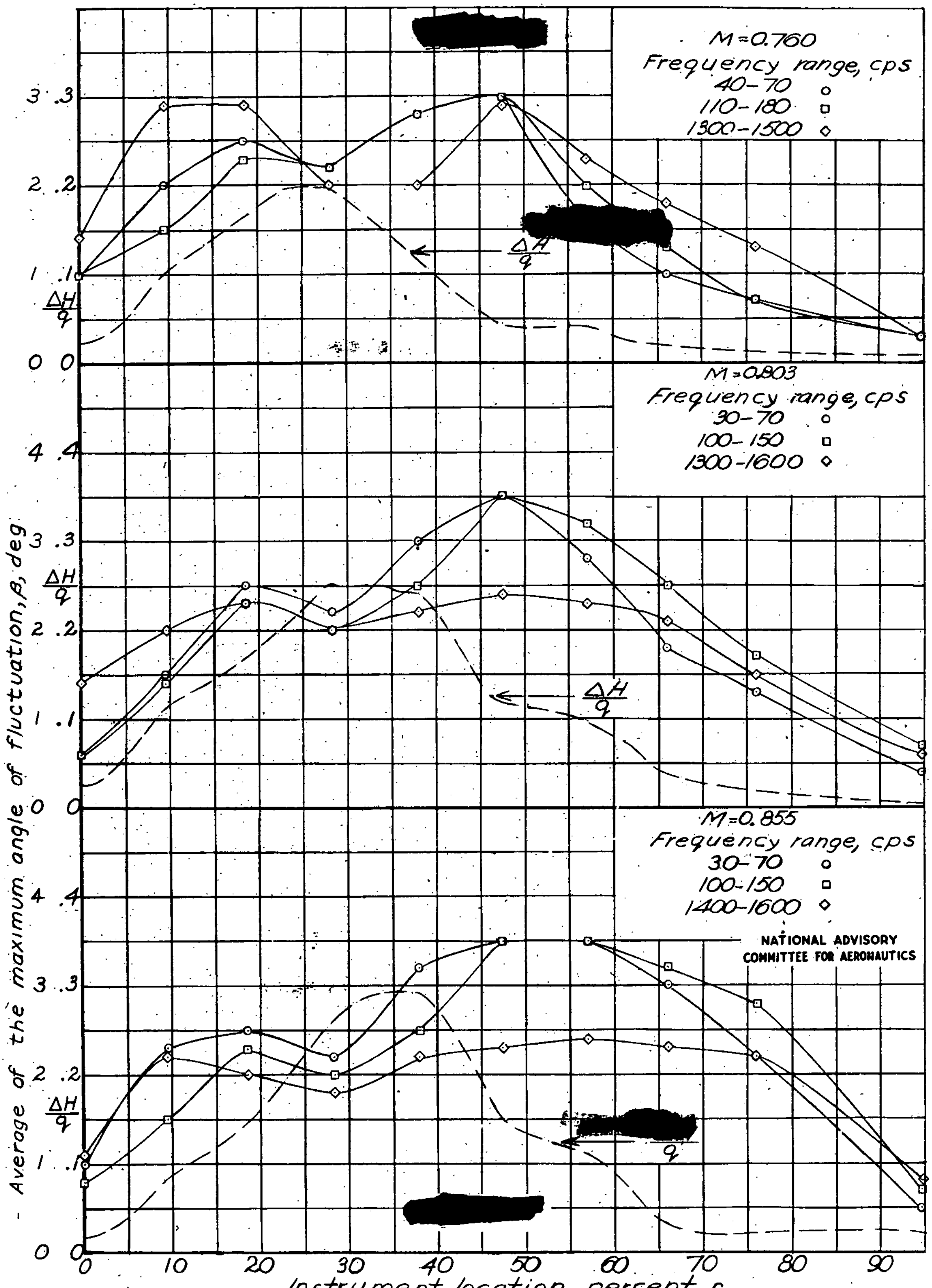


Figure 8.– Maximum angle of fluctuation as a function of instrument location. $\alpha = 7°$.

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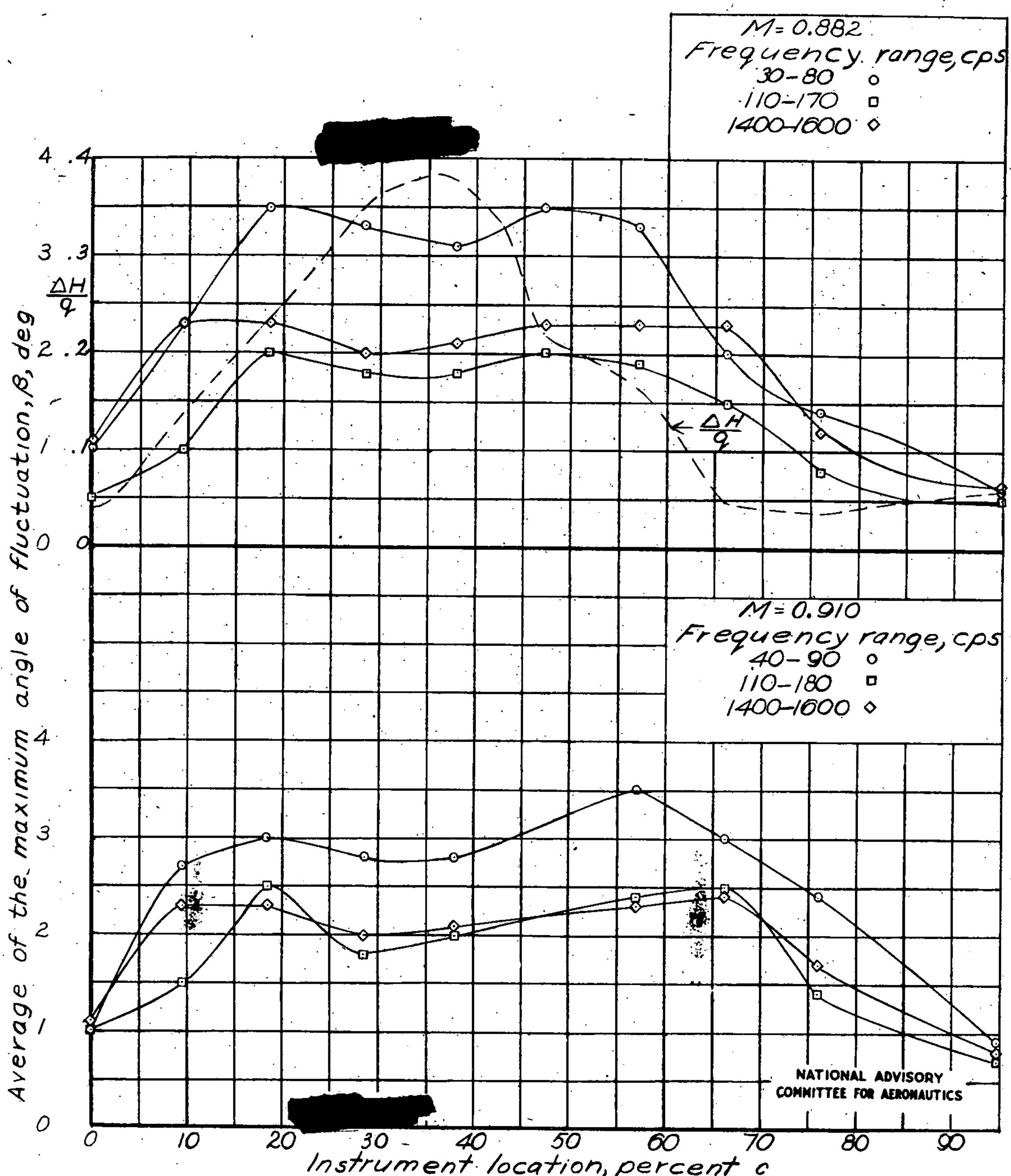


Figure 8.– Concluded. [redacted]

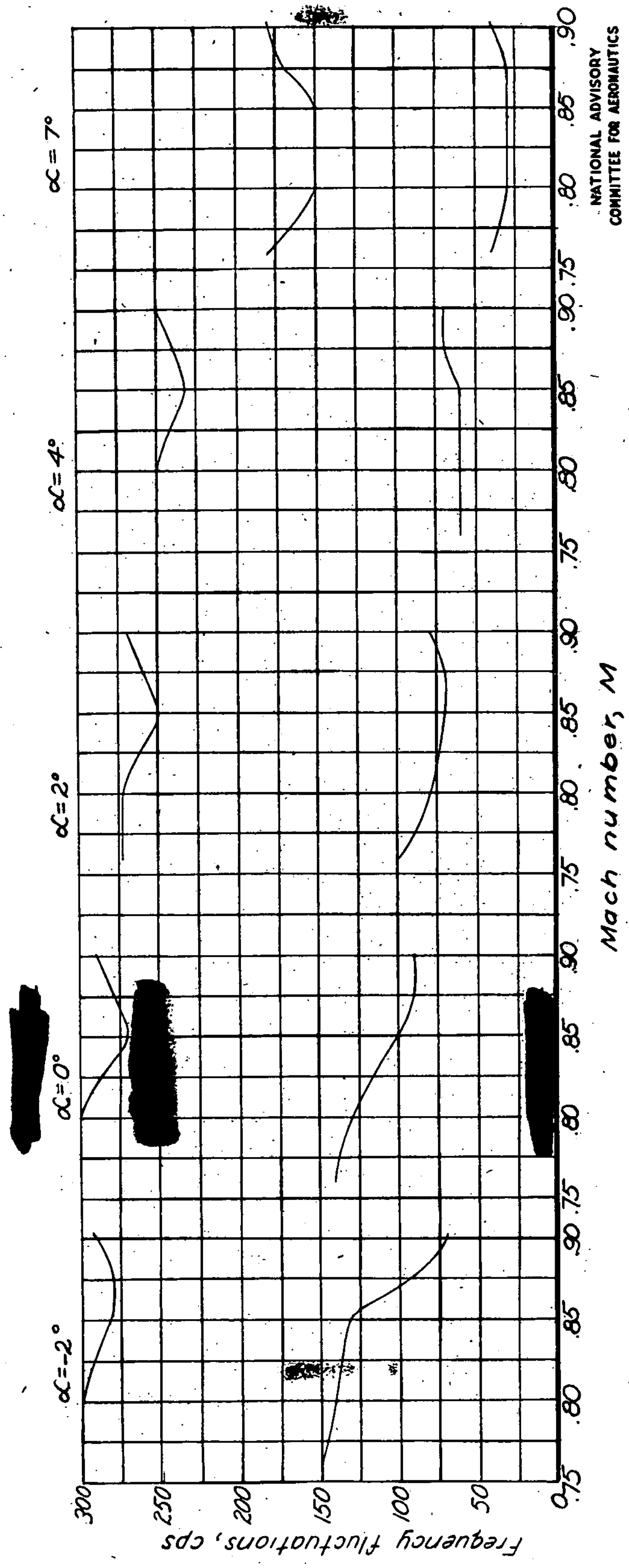


Figure 9.- Range of low-frequency fluctuation as a function of Mach number of the model.

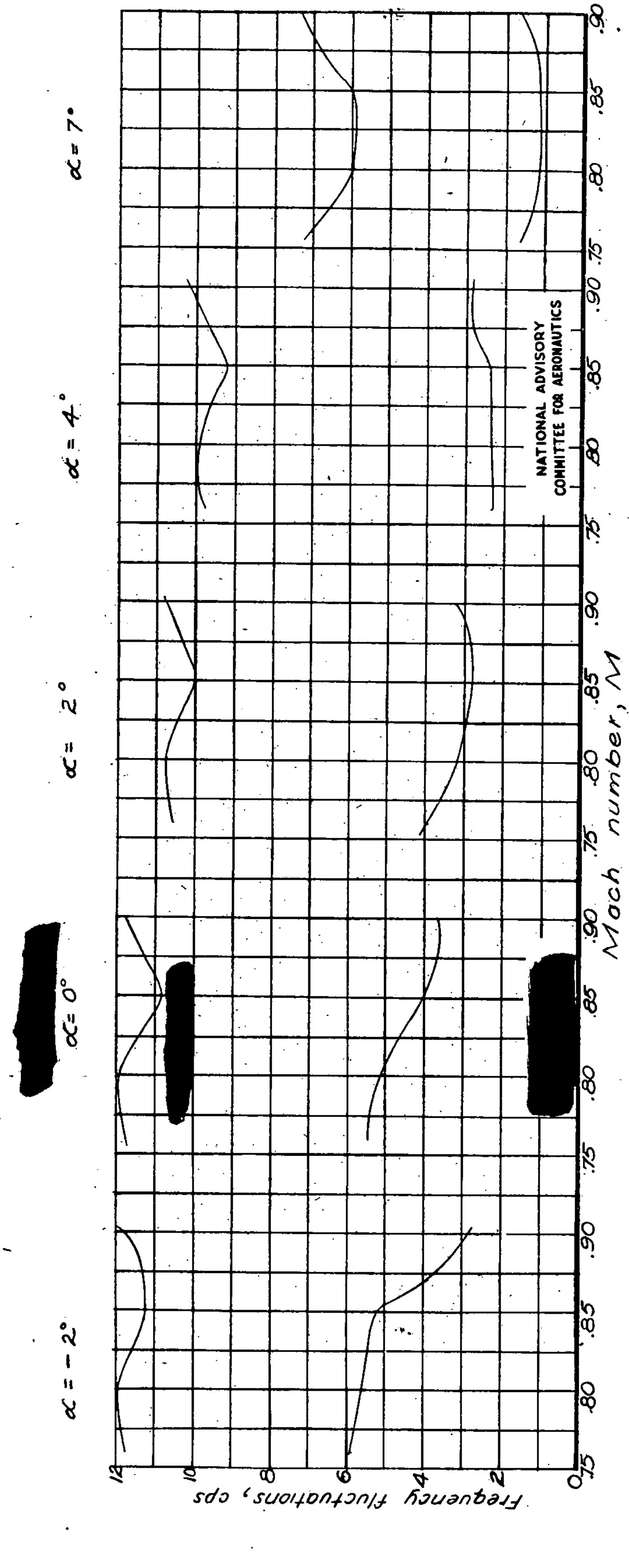


Figure 10:- Range of low-frequency fluctuation as a function of Mach number for full-scale conditions.

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